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# Coconino National Forest

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## FN708 Conceptual Remedial Strategies

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## **1.0 SITE DESCRIPTION**

Fossil Creek Road runs in a westernly direction from Strawberry, AZ to Fossil Creek. The Forest Service gate accessing the Fossil Creek watershed is approximately 4.9 miles from Strawberry. The road section of interest continues past the gate winding along the Fossil Creek canyon wall for approximately 4.1 miles ending at the first bridge encountered along the creek.

### **1.1 FIELD VISIT**

The field visit occurred in January, 2014. Deficiencies along the road were cataloged starting from the bottom, lowest elevation, and ending at the Forest Service gate. Numerous deficiencies were noted which included,

1. Rockfall hazards - Many jointed, loose rocks were noted all along the road. Rockfall was observed at many locations including large talus piles. Many of these hazards are located immediately adjacent to the road where there is little opportunity to construct a catchment. The road dips away from the primary rockfall source as it enters the canyon improving, and complicating, the issue.
  - a. The improvement is due the longer runout distance and intermediate benches that takes energy out of rolling rocks. The benches provide opportunity to trap rocks as they roll down the hill.
  - b. Complications arise due to the lack of access to the rockfall sources making remediation difficult.
2. Debris/rock avalanche chutes were identified all along the section of the road surveyed.
3. Road fill failures and scoured shoulders. Scour is the result of surface water runoff or water overtopping a road when the upstream end of a culvert is plugged.

Given the extent of deficiencies the intent of this report is to outline remedial strategies to address the deficiencies and approximate cost implementing the proposed remediation's.

### **1.2 EXPANDED FIELD EXPLORATION**

Should the decision be made to move forward with implementation of any conceptual remedial proposals forwarded in this report an expanded field exploration will be required in support of rockfall remediation designs or risk reduction efforts in general.

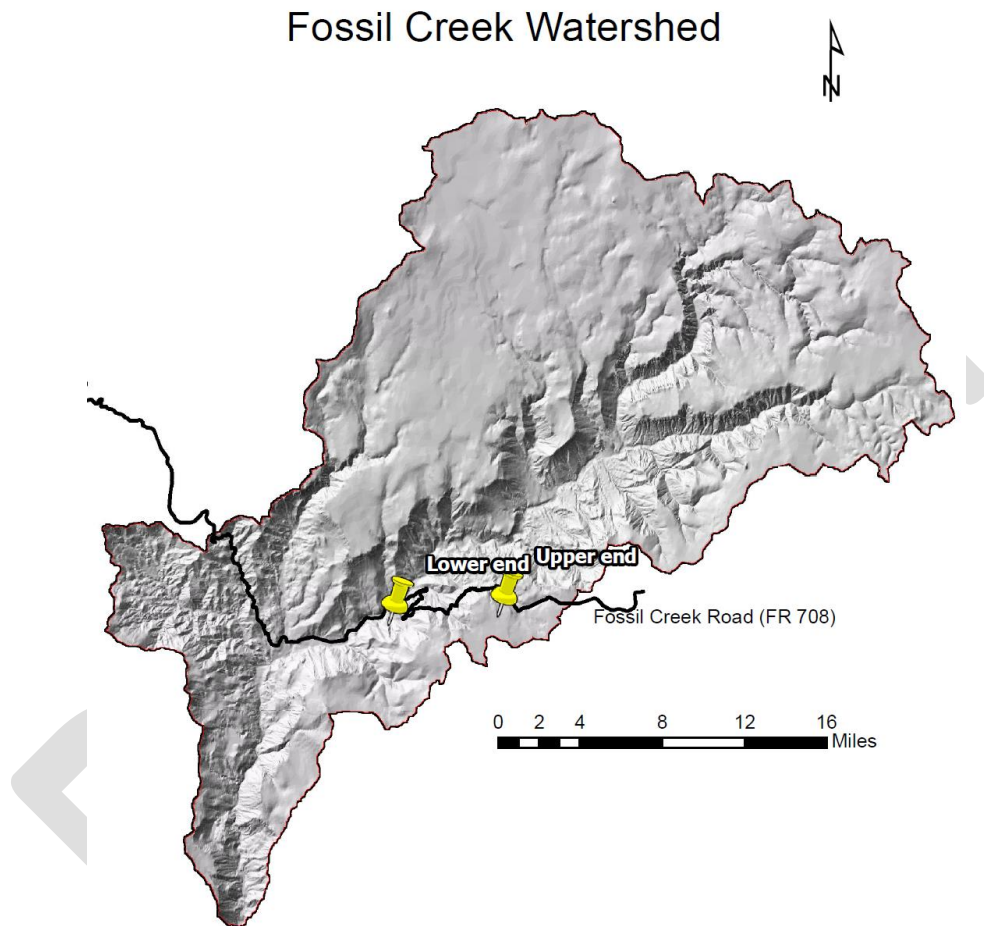
The expanded exploration would include the accurate mapping of the rockfall hazards to identify unstable blocks, large rocks, shear zones, faults, geologic features, ..etc. to allow a more accurate picture of the cost/benefit and feasibility of proposed alternatives to be developed.

LiDar mapping of the Fossil Creek watershed is required to maximize accuracy of hazard assessments conducted in the Fossil Creek watershed. Lidar mapping will enable the delineation

of hazard zones by hazard level (high, significant, and low) from various geohazards and strategies to mitigate risk associated with identified geohazards.

## 2.0 FOSSIL CREEK GEOHAZARDS

The Fossil Creek Watershed is approximately 99.3 square miles in size. It ranges in elevation from approximately 810 to 1925 meters.



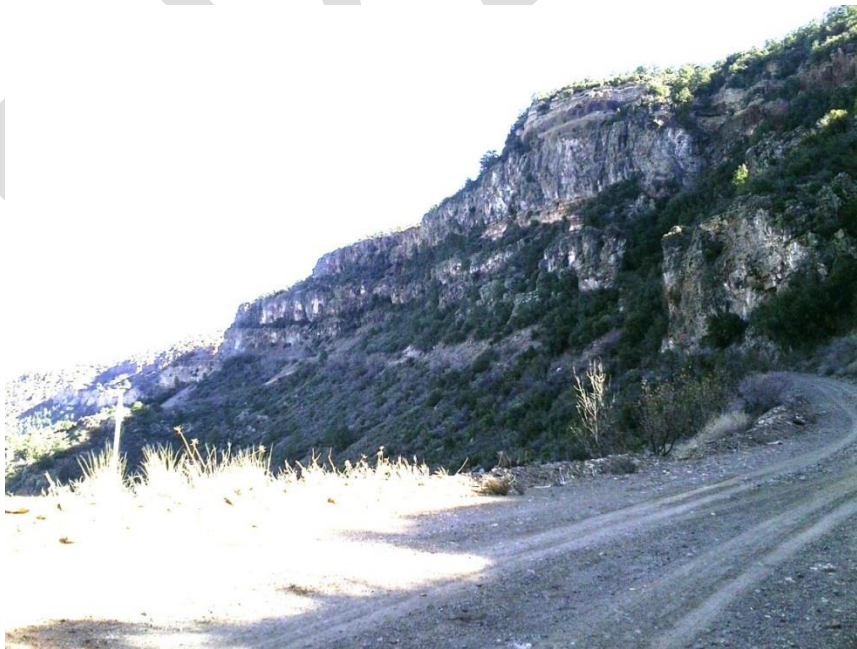
**Figure 1:** Fossil Creek watershed. Markers indicate approximate limits along Fossil Creek road viewed as most hazardous to pedestrians and motor vehicles.

The Fossil Creek watershed is susceptible to several geohazards which include rockfall, rock avalanche, debris flows, and flash flooding. A qualitative treatment of three of these geohazards is explored. Precipitation in the form of rainfall in the Fossil Creek watershed is a primary impetus to all four geohazards.

Fossil Creek road is susceptible to rock avalanche, debris flows, and rockfall events. Evidence of relatively recent events is apparent all along the section of Fossil Creek road contained within the Fossil Creek watershed. This is especially true in the upper reaches of the road where it enters the watershed.

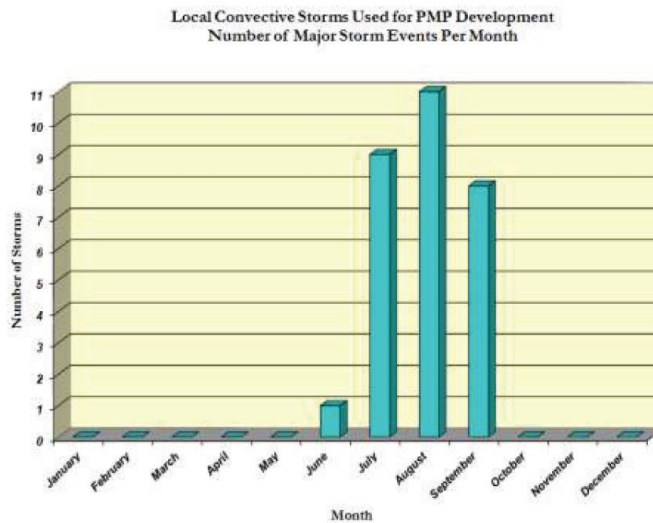


**Figure 2:** Red highlights indicate areas of recent rockfall, rock avalanche, and debris flow activity.



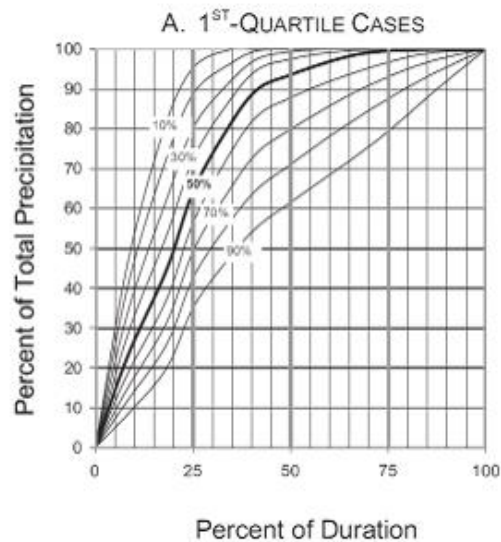
**Figure 3:** Example of rockfall/avalanche sources along Fossil Creek road.

Analysis of existing rainfall data, NOAA Atlas 14, and PMP studies conducted in Arizona show the distribution of significant rainfall events in the Fossil Creek watershed occur primarily in the months of July, August, and September – the peak recreation period.

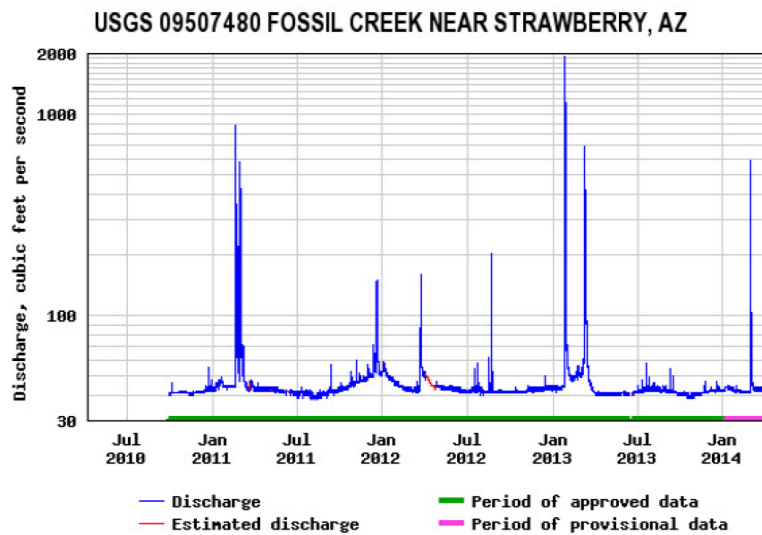


**Figure 4:** Distribution of local convective storms used in regional PMP study which includes the Fossil Creek Watershed.

Intense rainfall patterns have a positive correlation to flash floods, rockfall, rock avalanche, and debris flow events (M. Krautblatter, M. Moser 2009). In addition, a significant percentage of local storms that impact the Fossil Creek watershed appear to have a positive skew – a large proportion of the total rainfall generated by a storm event occurs at the beginning of the storm. Given the relatively short lead time – indication that rain is approaching – risk from such storms could be significantly elevated over other local storms with much more uniform rainfall distributions.



**Figure 5:** Distribution of total rainfall in 25% of storms impacting Fossil Creek watershed. Note positive skew.



**Figure 6:** Fossil Creek Stream Gauge. Note spike in stream flow in August of 2012 possibly indicating extreme storm event.

Due to the intersection of substantially increased peak usage and potential for extreme climatic conditions risk that pedestrians and motorists will encounter dangerous road conditions appears significant and will continue to increase as usage increases. A comprehensive geohazards evaluation will be required to quantify this risk – taking site conditions and usage trends into account.



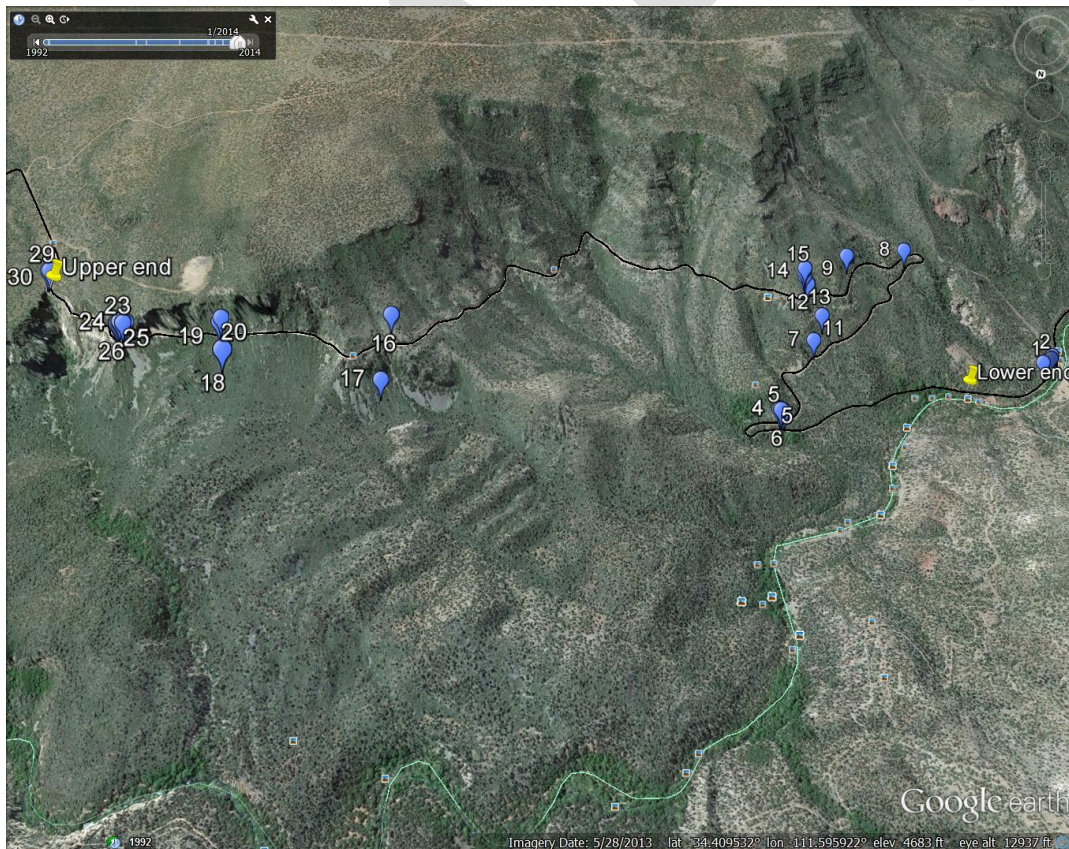
**Figure 7:** Typical congestion along Fossil Creek road. Note unmitigated rockfall hazard adjacent to parked cars and pedestrians.

The geohazards assessment should include qualitative and, possibly, quantitative (to include probabilistic analysis) evaluation of the geohazards in the Fossil Creek watershed using generally

accepted methods. Such an assessment would more accurately quantify periods of increased risk and identify particularly hazardous areas/zones where risk is greatest.



**Figure 8:** Example of rockfall event along Fossil Creek road



**Figure 9:** Location of proposed mitigations along Fossil Creek road.

### 3.0 MINOR ROCKFALL MITIGATION STRATEGIES

Minor rockfall hazard mitigation strategies applicable to Fossil Creek Road include,

- Scaling
- Rockfall netting
- Resloping
- Rockfall barriers

The lack of road width all along Fossil Creek road provide little opportunity for the construction of a significant catchment. Locations of interest, depicted by points 1 through 30 in Figure 9, are included in kmz which is included with this report.

#### 3.1 SCALING

Scaling involves the removal of loose and unstable material from the slope face either by hand or with the aide of machinery – excavator, lift, etc.. Low yield explosives are sometimes utilized in scaling efforts – especially in instances where safety of the Contractor might be an issue. Scaling must be repeated periodically as site conditions warrant.

Period of effectiveness – 2 to 10 years.



**Figure 10:** Hand scalers and heavy equipment removing loose material from slope (*from FHWA-CFL/TD-11-002*)

Points along Fossil Creek Road where applicable: All locations threatened by rockfall.

#### 3.2 ROCKFALL NETTING

Rockfall netting is designed to confine/slow/stop rockfall. It is typically attached using anchor trenches or through a rockbolt/cable system. The rockfall netting is draped across the rockfall source face.



**Figure 11:** California DOT cable netting project. Note jersey barriers installed as catchment impact barrier to trap material conveyed by the netting.

When rock breaks away from the rock face it interacts with the rockfall netting slowing its fall and damping the amplitude of the rock bounces. Rockfall is conveyed to the bottom of the rockfall drape where it can be easily removed. Twisted wire configurations are typically utilized for rock diameters less than 1 foot. Cable reinforcing and cable nets are deployed for larger diameter boulders. Design limitations of the various systems are detailed by the manufacturer.



**Figure 12:** Tennessee DOT rockfall abatement project – scaling and rockfall netting.

Period of effectiveness – 15 years to indefinite...depending on periodic maintenance.

Points along Fossil Creek Road where applicable: Mile post 0 to .3 and 2.1 to 4.7 approximately. pics 1 - 11 and 22 - 28.

### 3.3 RESLOPING

Resloping generally involves the reshaping/excavation of an existing slope to a more stable configuration. Resloping is usually accomplished by excavating with heavy equipment or through blasting - or in combination.



**Figure 13:** White line is one possible reconfiguration of existing slope – laying back slope and benching to install debris fence.

Period of effectiveness – indefinite. Dependent on periodic maintenance.

Points along Fossil Creek Road where applicable: Milepost 0 to .3 and 4.7 approximately.  
pics 1 - 3 and 22 - 25.

### 3.4 ROCKFALL IMPACT BARRIERS

Impact barriers are utilized to contain rockfall conveyed by rockfall netting or along sections of road subject to low velocity rockfall – rockfall generated by relatively short slopes – that has a low probability of bouncing over the barriers.



**Figure 14:** Jersey barriers installed along catchment protecting road from rockfall.  
(Courtesy [slidingthought.wordpress.com](http://slidingthought.wordpress.com))

Points along Fossil Creek Road where applicable: All locations

## 4.0 LARGE ROCKFALL MITIGATION STRATEGIES

### 4.1 SCALING AND ROCKBOLTING

The upper reaches of Fossil Creek road, MP 0 to .81 approximately, is subject to relatively frequent impacts from large rockfall 3 foot in diameter or larger.



**Figure 15:** Large rockfall sources MP .25 to .81

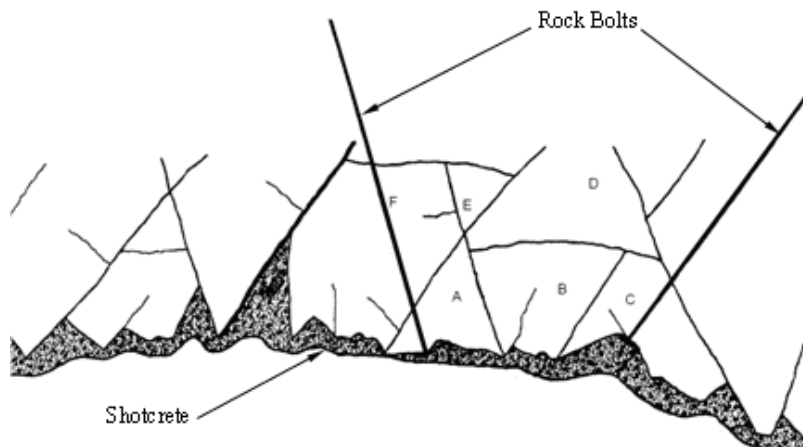
Given its proximity to the road, frequency of rockfall, apparent risk, and cost/benefit MP 0 to .3 is the section that offers the highest stabilized benefit.



**Figure 16:** Example of slope face adjacent to road MP 0 - .3

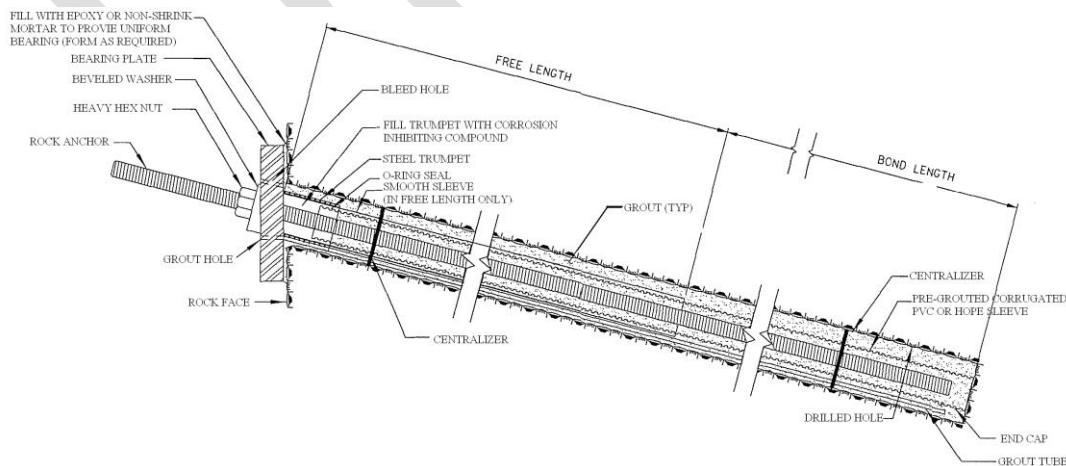
Scaling is first employed to remove loose, unstable, rock. Scaling of such a large volume of large rocks could be accomplished via mechanical means or through the careful placement of low yield explosives. Each area of instability would require significant planning and relatively intensive execution to insure safety and environmental concerns are addressed.

Generally accepted structural stabilization techniques include rock bolting primarily. A precursor to the development of any rock bolting plan is a detailed mapping of the rock face by a structural/engineering geologist. Such a mapping program will identify sources of instability in the slope face - joints, faults, and blocks – so that an effective/economical bolting plan can be developed.



**Figure 17:** Strategic placement of rockbolts to stabilize blocks that control overall stability of rockface. (Courtesy FHWA)

Once the rock bolts are installed to address local stability issues along the rock face rockfall netting or shotcrete is typically employed to abate long term rockfall risk from weathering.



**Figure 18:** Typical rockbolt section (Courtesy FHWA)

Reinforcement (rebar, welded wire) is sometimes installed over the rock face and shotcreted to provide structural support to the entire rock face at issue. Given the relatively narrow road prism along fossil creek road shotcreting may be required to insure risk is adequately addressed.



**Figure 19:** Installation of reinforced shotcrete face (*Courtesy FHWA*)

## 4.2 RESLOPING

Resloping incorporates blasting primarily to achieve a stable final slope configuration or remove large unstable rock safely. Removal of large quantities of rock economically would likely require high yield blasting.

## 4.3 MULTIFACETED APPROACH

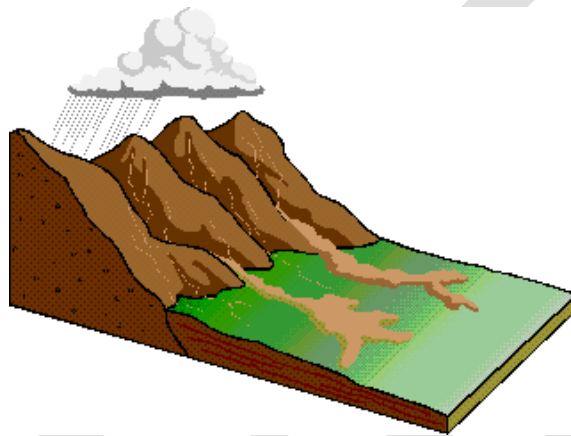
A multifaceted approach could be employed to achieve a satisfactory outcome. It could be accomplished sequentially in the following order in most cases,

1. Low yield blasting to remove large unstable rocks
2. Scaling to remove small unstable rocks
3. Targeted spot bolt placement to stabilize large blocks
4. Local shotcrete program to stabilize high risk sections of rock face
5. Installation of rockfall netting to capture/convey residual unstable material
6. Installation of rockfall barriers or debris fence along toe to keep material conveyed by the rockfall netting from entering the road prism.

Points along Fossil Creek Road where applicable: Mile post 0 to .3 and 4.7 approximately.

## 5.0 DEBRIS FLOWS AND ROCK AVALANCHE

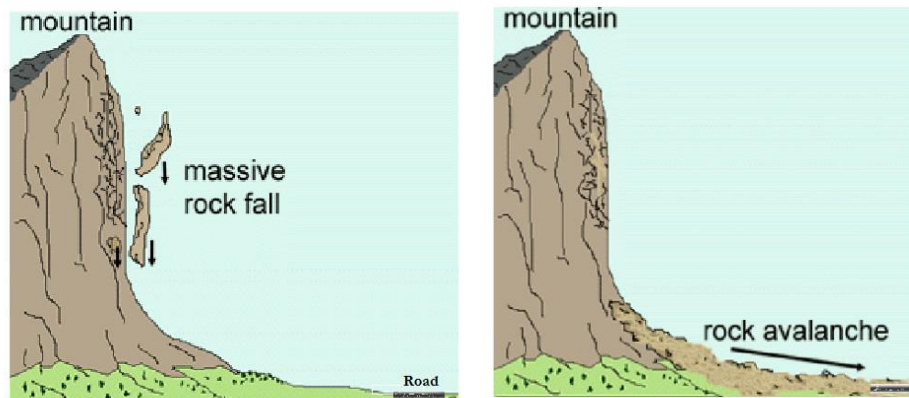
Debris flows are driven by rainfall. In the case of fossil creek road debris flows are likely generated by concentrated surface runoff being channeled by crevices in the rock face. Accumulated debris in those crevices is entrained by the high velocity flowing water which carries the material downslope. As the debris enters the road prism culverts are often plugged sending the remaining debris over the road surface. Since a significant amount of material is often entrained in the flow the scour potential is usually high which results in removal/entrainment of roadbed materials as the debris flow crosses the road. Ultimately, a trench is created making it impossible for traffic to cross.



**Figure 20:** Example of channelized debris flow generation and outcome (*Courtesy of USGS*).

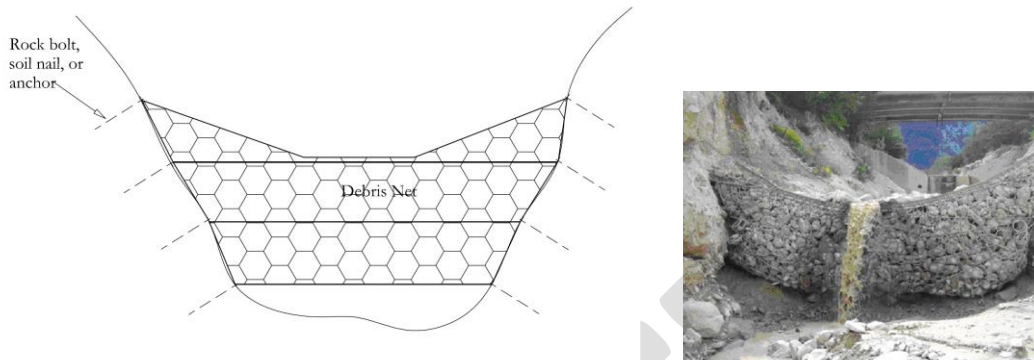
Rock avalanche are generated when a large rock formation breaks away from the rock face. Upon impact with the slope surface the rock shatters sending a cascading debris pile downslope.

Rock avalanches can happen in wet or dry condition though they are most common during intense rainfall events or as a result of freeze/thaw actions.

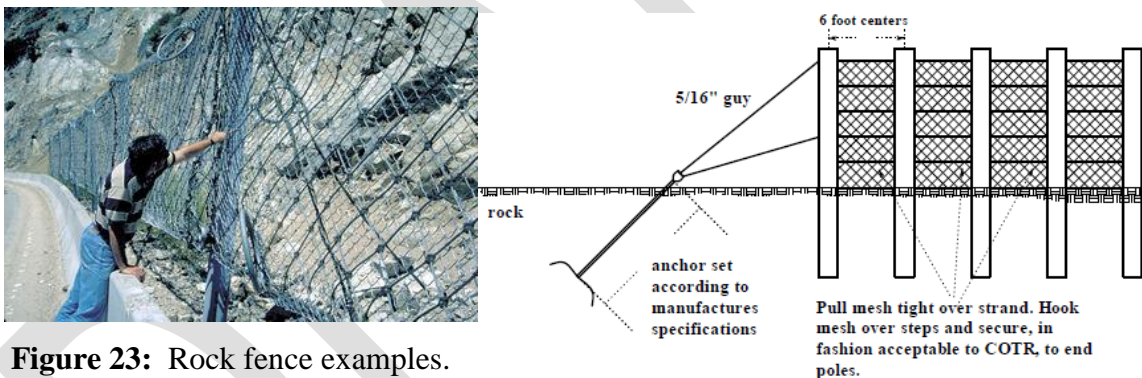


**Figure 21:** Example of rock avalanche threat to road (*Courtesy of Prof. Brad Perry, CSU Long Beach*).

Remediation strategies for rock avalanches range from confined soil abutments, rock impact barriers, to rock nets/fences. Given the relatively narrow road prism rock nets and fences would likely be the most feasible option.



**Figure 22:** Rock net (*Courtesy of Swiss Federal Institute for Forest, Snow and Landscape Research WSL*)

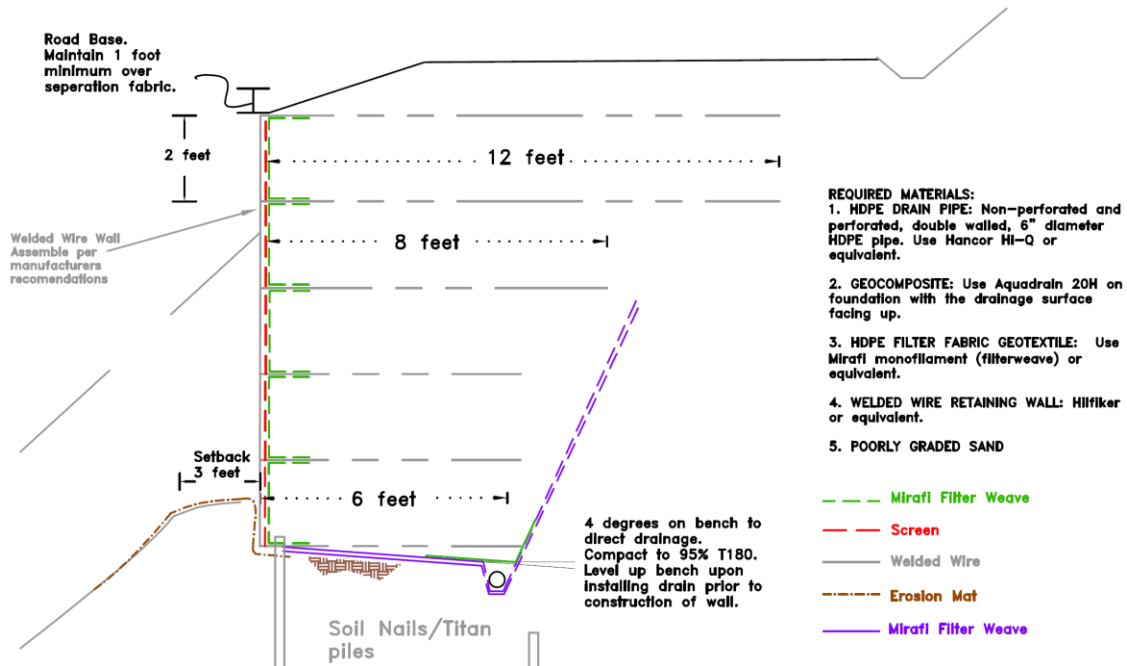


**Figure 23:** Rock fence examples.

Points along Fossil Creek Road where applicable: Mile post 0 to 1, approximately.

## 6.0 SHALLOW ROAD FILL FAILURES

Due to the likelihood of intense rainfall over the life of any structure installed to repair road fill failures in the Fossil Creek watershed storm proofing remediation strategies should be employed. The most economical solution will be the installation of mechanically stabilized earth or rock walls (MSE or MSR). Welded wire walls are the most constructible and cost competitive. However, alternative configurations could be considered and are dependent on project budget limitations



**Figure 24:** Typical MSE configuration.

## 7.0 CONCLUDING REMARKS

All the mitigation strategies outlined require periodic maintenance. In the case of Fossil Creek road the annual maintenance could be substantial. APS was responsible for maintenance on Fossil Creek road up to 2007 when APS relinquished water diversion rights. According to APS the maintenance budget for Fossil Creek road averaged approximately \$180,000 per year. Implementation of the risk reduction strategies indicated will likely reduce the annual maintenance budget though magnitude of those reductions would be difficult to quantify.

Additionally, the variance in that average maintenance budget could be substantial given the high likelihood of significant rockfall, debris, and rock avalanche events. That variance may or may not be reduced with the implementation of the indicated improvements.

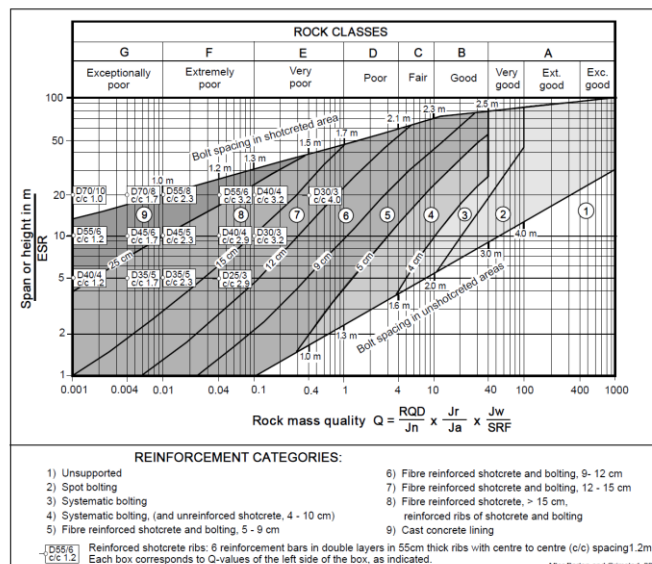
## 8.0 ESTIMATED COST

### 8.1 BLASTING

Alternatives that include blasting operations would likely be confined to MP 0 to .25 and MP 4.7 – approximately. Intervening locations could be incorporated in the blasting program however. It is assumed blasting operations would utilize low yield type primarily. Gauging the total amount of rock removal is subjective. Based on photographic information and the initial field visit a minimum 10 feet of material would require removal from the rock face to achieve a stable configuration. Based on that estimate approximately 800,000 cubic feet of rock could be removed. At 180 lbs/cuft the total tonnage of rock removed would be approximately 57,000 tons. The unit costs for blasting could range between \$5 and \$14 per ton. Blasted rock would require secondary processing for haul and disposal. Cost for processing rock for haul would be about \$5 per ton. If a waste site is close haul and disposal would run about \$10 to \$15 per ton. Total cost for blasting would be approximately \$1.1 to \$1.7 million. Blasting cost could be substantially reduced as the result of a comprehensive investigation by an engineering geologist.

### 8.2 ROCK BOLTING

Alternatives that include a rock bolting program would likely be focused on spot bolting of segmented rock blocks, fissures, or other zones exhibiting potential for instability. The cost associated with spot bolting depends on access and difficulty. The area that spot bolting is most likely to be incorporated in any alternative is from MP 0 to .25. The unit cost of spot bolting is approximately \$200 per linear foot. Assuming a minimum 20 foot installed length and an average spot bolting radial spacing of approximately 15 feet total cost could exceed \$600,000.



**Figure 25: Rockbolting Q chart.**

### **8.3 SCALING**

Scaling would be included in all remedial alternatives considered. The unit cost for scaling activities currently range between \$150 and \$200 per hour. The estimated time required to scale all identified rockfall hazards – an estimated 17,000 square yards of slope/rock face - is between 300 and 600 hours. The total scaling cost is estimated to be between \$45,000 and \$120,000 – not including mob/demob, cleanup, and disposal.

### **8.4 ROCKFALL NETTING**

Rockfall netting would include cable and twisted wire. The slope/rock face requiring rockfall netting coverage is approximately 100,000 square feet. The unit installed cost for rockfall netting currently ranges between \$8 and \$12 per square foot face installed putting the total cost between \$800,000 and \$1,200,000.

### **8.5 DEBRIS/ROCKFALL BARRIERS**

#### **8.5.1 Debris Nets**

Debris nets are utilized to trap debris flows and rock avalanche before they impact Fossil Creek road. Nets would be installed on an as needed basis. The exact number would be determined as part of an engineering geologist assessment for debris flow potential from all sources. The unit cost for a debris net installation is dependent on that evaluation.

#### **8.5.2 Debris Fences**

Debris fences function similarly to debris nets. The same limitations outlined for debris nets apply to debris fences. Unit cost for debris fences are between \$200 and \$300 a linear foot installed. The number of linear feet required is dependent on the engineering geologist evaluation.

#### **8.5.3 Debris Impact Barriers**

Debris impact barriers are designed to prevent rockfall from entering the roadway. The barriers come in many forms which include compacted reinforced earth structures and Jersey barriers. Unit cost for Jersey barrier installation is approximately \$50 a linear foot. The total cost for impact barrier installation would be between \$100,000 and \$150,000.

## 8.6 RETAINING WALLS

Retaining walls reinforce/retain soils in sections of roadway that are unstable or damaged. Damage along Fossil Creek results from uncontrolled drainage, rockfalls, rock avalanches, and debris flows. Consequently, all options considered have a durable face that can withstand scour resulting from debris and water. Mechanically stabilized earth walls (MSE) are the lowest cost option available of the alternatives considered. They are flexible and have a high degree of constructability. Approximately 2000 square feet of MSE walls are required along Fossil Creek to reestablish or stabilize the roadway. The cost per square foot is approximately \$65 putting the total cost for retaining wall construction at approximately \$130,000.

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